

TECHNICAL FIELD OF THE INVENTION

This invention relates to methods of treating presbyopia, hyperopia, primary open angle glaucoma and ocular hypertension and more particularly to methods of treating these diseases by increasing the effective working distance of the ciliary muscle. The invention also relates to increasing the amplitude of accommodation of the eye by increasing the effective working range of the ciliary muscle.

BACKGROUND OF THE INVENTION

In order for the human eye to have clear vision of objects at different distances, the effective focal length of the eye must be adjusted to keep the image of the object focused as sharply as possible on the retina. This change in effective focal length is known as accommodation and is accomplished in the eye by varying the shape of the crystalline lens. Generally, in the unaccommodated emmetropic eye the curvature of the lens is such that distant objects are sharply imaged on the retina. In the unaccommodated eye near objects are not focused sharply on the retina because their images lie behind the retinal surface. In order to visualize a near object clearly, the curvature of the crystalline lens is increased, thereby increasing its refractive power and causing the image of

the near object to fall on the retina.

The change in shape of the crystalline lens is accomplished by the action of certain muscles and structures within the eyeball or globe of the eye. The lens is located in the forward part of the, immediately behind the pupil. It has the shape of a classical biconvex optical lens, i.e., it has a generally circular cross section having two convex refracting surfaces, and is located generally on the optical axis of the eye, i.e., a straight line drawn from the center of the cornea to the macula in the retina at the posterior portion of the globe. In the unaccommodated human eye the curvature of the posterior surface of the lens, i.e., the surface adjacent to the vitreous body is somewhat greater than that of the anterior surface. The lens is closely surrounded by a membranous capsule that serves as an intermediate structure in the support and actuation of the lens. The lens and its capsule are suspended on the optical axis behind the pupil by a circular assembly of very many radially directed collagenous fibers, the zonules, which are attached at their inner ends to the lens capsule and at their outer ends to the ciliary body, a muscular ring of tissue located just within the outer supporting structure of the eye, the sclera. The ciliary body is relaxed in the unaccommodated eye and therefore assumes its largest diameter. According to the classical theory of accommodation, originating with Helmholtz, the

relatively large diameter of the ciliary body in this condition causes a tension on the zonules which in turn pull radially outward on the lens capsule, causing the equatorial diameter of the lens to increase slightly and decreasing the anterior-posterior dimension of the lens at the optical axis. Thus, the tension on the lens capsule causes the lens to assume a flattened state wherein the curvature of the anterior surface, and to some extent of the posterior surface, is less than it would be in the absence of the tension. In this state the refractive power of the lens is relatively low and the eye is focused for clear vision of distant objects.

When the eye is intended to be focused on a near object, the muscles of the ciliary body contract. According to the classical theory, this contraction causes the ciliary body to move forward and inward, thereby relaxing the outward pull of the zonules on the equator of the lens capsule. This reduced zonular tension allows the elastic capsule of the lens to contract causing an increase in the antero-posterior diameter of the lens (i.e., the lens becomes more spherical) resulting in an increase in the optical power of the lens. Because of topographical differences in the thickness of the lens capsule, the central anterior radius of curvature decreases more than the central posterior radius of curvature. This is the accommodated condition of the eye wherein the image of near

objects falls sharply on the retina.

Presbyopia is the universal decrease in the amplitude of accommodation that is typically observed in individuals over 40 years of age. In the person having normal vision, i.e., having emmetropic eyes, the ability to focus on near objects is gradually lost, and the individual comes to need glasses for tasks requiring near vision, such as reading.

According to the conventional view the amplitude of accommodation of the aging eye is decreased because of loss of elasticity of the lens capsule and/or sclerosis of the lens with age. Consequently, even though the radial tension on the zonules is relaxed by contraction of the muscles of the ciliary body, the lens does not assume a greater curvature. According to the conventional view, it is not possible by any treatment to restore the accommodative power to the presbyopic eye. The loss of elasticity of the lens and capsule is seen as irreversible, and the only solution to the problems presented by presbyopia is to use corrective lenses for close work, or bifocal lenses, if corrective lenses are also required for distant vision.

Certain rings have been used in ocular surgery for various purposes. Rings of flexible and/or elastic material, prepared in situ by fastening the ends of strips of the material around the generally posterior portion of the globe have been used to compress

the sclera in certain posterior regions. Supporting rings of metal, adapted to fit the contour of the sclera have been used as temporary supporting structures during surgery on the globe. However, none of these known devices have been used for surgical
5 treatment of presbyopia, and none have been adapted to the special needs of prosthetic devices used in treating presbyopia.

Accordingly, a need has continued to exist for a method of treating presbyopia that will increase the amplitude of accommodation of the presbyopic eye, thereby lessening or
10 eliminating the need for auxiliary spectacle lenses to relieve the problems of presbyopia.

SUMMARY OF THE INVENTION

A method of treating presbyopia and other eye disorders has now been found which comprises increasing the effective working distance of the ciliary muscle in the presbyopic eye.

5 Accordingly it is an object of the invention to provide a method for treating presbyopia.

A further object is to provide a method for treating presbyopia by increasing the effective working distance of the ciliary muscle in the presbyopic eye.

10 A further object is to provide a method for treating presbyopia by increasing the radial distance between the equator of the crystalline lens and the ciliary body.

15 A further object is to provide a method of treating presbyopia by suturing a scleral expansion band to the sclera of the globe at the location of the ciliary body.

A further object is to provide a method of treating presbyopia by weakening the sclera in the region of the ciliary body.

20 A further object is to provide a method of treating presbyopia by arresting the growth of the crystalline lens in the presbyopic eye.

A further object is to provide a method of treating presbyopia by shortening the zonules in the presbyopic eye.

A further object is to provide a method of treating presbyopia

by shortening the ciliary muscle or moving its insertions.

A further object is to provide a treatment for hyperopia.

A further object of the invention is to provide a treatment for primary open angle glaucoma.

5 A further object is to provide a treatment for ocular hypertension.

A further object is to provide a method for increasing the amplitude of accommodation of the eye.

10 Further objects of the invention will become apparent from the description of the invention which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 shows an isometric view of a scleral expansion band of this invention;

FIGURE 2 shows an anterior elevational view of the band of
5 FIGURE 1;

FIGURE 3 shows a posterior elevational view of the band of
FIGURE 1;

FIGURE 4 shows a side view of the band of FIGURE 1.

FIGURE 5 shows a lateral sectional view of the band of
10 FIGURE 2;

FIGURE 6 shows a posterior elevation view of another
embodiment of the scleral expansion band of the invention which
uses pins for fixation;

FIGURE 7 shows a lateral sectional view of the band of
15 FIGURE 6;

FIGURE 8 shows a posterior elevation view of another
embodiment of the scleral expansion band of the invention which
uses tangentially extending fixation pins;

FIGURE 9 shows a lateral sectional view of the band of
20 FIGURE 8;

FIGURE 10 shows a diagram of an exemplary laser of the type
capable of treating various eye diseases in accordance with the
principles of the present invention; and

FIGURE 11 shows an exemplary flow diagram of an exemplary method of operating a laser in accordance with the principles of the present invention.

FIGURE 11 shows an exemplary flow diagram of an exemplary method of operating a laser in accordance with the principles of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

This invention is based on a different theory, developed by the inventor, regarding the cause of the loss of amplitude of accommodation that constitutes presbyopia. According to this view, accommodation in the non-presbyopic eye is not due to relaxation of the lens and capsule when the zonular tension is relaxed as a result of the contraction of the ciliary body. On the contrary, the contraction of the ciliary body, exerts a tension on the zonular fibers that in turn actually results in an increase in the equatorial diameter of the lens. However, the increased zonular tension causes a decrease in the peripheral volume of the lens that in turn results in a corresponding increase in the central volume of the lens. These regional volume changes in the lens are responsible for the change in optical power of the lens. This view differs from all previous theories of the mechanism of accommodation and its loss in presbyopia, in particular from Tscherning's theory which required the vitreous and attributed presbyopia to an enlargement of the nucleus of the lens. From the inventor's point of view, the difference between the change in the central anterior radius of curvature and the change in the central posterior radius of curvature which occurs in accommodation is explained by the force distribution generated by the zonular attachment to the lens and is not dependent on the topographical

thickness of the elastic capsule of the lens, the vitreous, or pressure changes which occur between the anterior and posterior chambers, explanations which have been proposed in the prior art. According to the theory of this invention, presbyopia results when the distance between the ciliary body and the equator of the lens and its capsule becomes less with age as a result of the normal growth of the lens. The lens, being of ectodermal origin, continues to grow throughout life, albeit slowly. The rate of increase of the equatorial diameter is approximately 0.02 millimeters per year. On the other hand, the dimensions of the scleral shell of the eye, which is of mesodermal origin, do not increase significantly after about age 13 in a normally emmetropic, hyperopic or myopic eye. Consequently, the radial distance between the equator of the lens and capsule and the ciliary body, i.e., the distance measured perpendicularly to the optical axis in the plane of the ciliary body, decreases throughout life. It is well known in muscle physiology that as the length of the effective range of pull of a muscle, i.e., its effective working distance, is reduced, its effective force is reduced in a linear fashion. Since the distance between the ciliary body and the lens equator is decreasing throughout life, it is to be expected according to the theory of the invention that there would be a corresponding linear decrease in the amplitude of accommodation, as observed (Alpern, M., in The

Eye, H. Dayson, Ed., Academic Press, New York, 1969, pp. 237-238), which would lead eventually to presbyopia.

According to the invention presbyopia is treated by increasing the effective working distance of the ciliary muscle. A number of procedures are available to the surgeon which can accomplish this increase in effective working distance.

A straightforward method of increasing the effective working distance of the ciliary muscle is to increase the distance between the equator of the crystalline lens and the inner diameter of the ciliary body in the presbyopic eye. This increased distance restores, at least to some extent, the distance through which the muscles of the ciliary body can contract, and thereby restores their ability to exert force on the lens and change its shape to accomplish accommodation. Any method that increases the radial distance between the lens and the ciliary body is effective in the method of this invention.

The effective working distance of the ciliary muscle can also be increased by shortening the zonules that connect the ciliary muscle to the equator of the crystalline lens. Similarly, procedures that shorten the body of the ciliary muscle itself or move its insertions in the scleral spur and the choroid can be employed to increase the effective working distance of the muscle. Finally, procedures that arrest the growth of the lens can stop the

steady loss of amplitude of accommodation, and such procedures are considered as fully within the scope of this invention.

It is preferred to increase the lens-ciliary body radial distance by increasing the diameter of the sclera in the region of the ciliary body. Any method that can accomplish such an increase
5 in the diameter of the sclera is considered to fall within the scope of the invention.

A preferred method of increasing the diameter of the sclera in the region of the ciliary body is to fasten to the sclera in that region a relatively rigid band having a diameter slightly larger than the section of the globe of the eye in the region of the ciliary body. In this way the sclera in that region is stretched and expanded so that the diameter of the circle describing the intersection of the plane of the ciliary body with the sclera is
10 slightly increased. The ciliary body, located immediately inside the globe and attached to the sclera in this expanded region is thereby also increased in diameter.
15

Thus, the scleral expansion band of the invention adapted for fastening to the sclera of a human eyeball in the region of the ciliary body comprises an anterior rim and a posterior rim, the
20 anterior rim being sized to lie adjacent to the anterior portion of a segment of the sclera of the human eyeball overlying the ciliary body of the eyeball and the posterior rim being sized to lie

adjacent the posterior portion of the scleral segment, and rigid structural means extending between the rims and spacing said rims apart so that the anterior rim will lie outside the anterior portion of the scleral segment when the posterior rim lies outside
5 the posterior portion of said scleral segment. The anterior rim, the posterior rim and/or the rigid structural means connecting the rims has a diameter greater than the exterior diameter of the scleral segment adjacent thereto.

Thus, the scleral expansion band of the invention is adapted
10 to be fitted to the sclera of the globe in the region of the ciliary body. The band will have, at least in part, a diameter slightly greater than that of the sclera at the location where it is to be attached. When the band is fitted to the sclera and firmly attached thereto it will exert a radially outward tension on the
15 sclera which expands the sclera and the underlying ciliary body. The scleral expansion band of the invention may be fastened to the sclera by any conventional surgical method. For example, the band may be a smooth solid band and be sutured to the sclera with sutures passing around the body of the band. A preferred band of
20 the invention is provided with suturing holes through which the sutures may be passed. The band may also be fastened with conventional surgical staples or clips as are well known in the ocular surgery art. The band may be provided with projections or

cut-out portions that can be used as anchoring points for sutures. The band may also be provided with projecting pins or the like which are inserted into or under the sclera to position the band and exert the appropriate radially outward tension. These pins may
5 extend in an anterior and/or a posterior direction from the band, and may project from one or both rims of the band or from the web portion connecting the rims. The pins may also project in a generally tangential direction from the rims or the inside of the web and be provided with sharpened tips or the like whereby they
10 will penetrate the sclera when the band is rotated and cause the sclera to be firmly fixed to the band and expanded. The band may also be adhesively fastened to the sclera with any physiologically acceptable surgical adhesive. A preferred surgical adhesive is a surgical grade cyanoacrylate adhesive. Mussel
15 adhesive protein may also be used as a suitable adhesive.

A preferred embodiment of the scleral expansion band of the invention is illustrated in FIGS. 1-5. The band 102 has a low frustoconical shape and has a posterior rim 106 and an anterior rim 108, with a web 104 extending between the rims. The band may be
20 provided with one or more holes 110 to assist in suturing the band to the sclera. The anterior rim 106 and the posterior rim 108 are both of generally circular shape. The taper in the diameter of the band is preferably selected in an individual case to fit the globe

in the region of the ciliary body. Accordingly, a preferred band has a low frustoconical having a circular base about 20 millimeters in diameter. The radial thickness of the band will be determined by the rigidity required in the band and the strength of the material from which it is made. Typically the radial thickness of the band will be about 0.1 to 0.75 millimeters depending on the rigidity of the substance used to make the band. The diameter of the anterior rim 106 of the band will be determined by the size of the globe in the patient to be treated. Accordingly, different sizes of band are available wherein the lesser diameter ranges from about 14.5 millimeters to about 18.0 millimeters in 0.25 millimeter increments. The axial width of the band will typically be about 2 millimeters.

An alternate embodiment of the scleral expansion band of the invention adapted to be fixed to the sclera by pins is illustrated in FIGS. 6 and 7. In this embodiment posterior pins 112 are fixed to the band and extend therefrom in a posterior direction while anterior pins 114 extend in an anterior direction.

Another embodiment of the band of the invention using interior tangentially-directed pins 114 is illustrated in FIGS. 8 and 9. This embodiment can be easily installed by placing it in position on the globe and rotating it to cause the tangential pins to penetrate the sclera and fasten it firmly to the band. This

embodiment can be easily removed at a later time by merely rotating it in the opposite direction to withdraw the pins from the sclera.

The scleral expansion band of the invention is made of a material that is sufficiently rigid to exert a force on the sclera sufficient to produce the radial expansion required by the method of the invention and that is physiologically acceptable for long-term implantation or contact with the ocular tissues. Such materials are well-known in the surgical art and include suitable metals, ceramics, and synthetic resins. Suitable metals include titanium, gold, platinum, stainless steel, tantalum and various surgically acceptable alloys, and the like. Suitable ceramics may include crystalline and vitreous materials such as porcelain, alumina, silica, silicon carbide, high-strength glasses and the like. Suitable synthetic resins include physiologically inert materials such as poly(methyl methacrylate), polyethylene, polypropylene, poly(tetrafluoroethylene), silicone resins and the like. The band may also be made of composite materials incorporating a synthetic resin or other matrix reinforced with fibers of high strength material such as glass fibers, boron fibers, carbon fibers, alumina fibers or the like. Thus, the band may be made of glass-fiber-reinforced epoxy resin, carbon fiber reinforced epoxy resin, carbon fiber reinforced carbon (carbon-carbon), or the like. A preferred material is surgical grade

poly(methyl methacrylate).

The scleral expansion band of the invention may be manufactured by any conventional technique appropriate to the material used, such as machining, injection molding, heat molding and the like.

The scleral expansion band may also be made in a plurality of parts that can be assembled prior to use or may be installed separately to form a complete band. The band may be adjustable in circumference. For example the band may be formed from a strip of material, e.g., metal or synthetic resin, with overlapping ends so that the ends may slide past one another thereby adjusting the circumference of the band. The length of the overlap may be adjusted, for example, by means of a tangential screw mechanism to adjust the circumference of the band and thereby the amount by which the sclera is expanded.

In practicing the method of the invention, the surgeon locates the proper region of the sclera to be expanded by measuring a distance of 1.5 millimeters posterior of the limbus. At this point the diameter of the circle of sclera surrounding the ciliary body is carefully measured and a band is selected having a minor diameter about 0.5 millimeter greater than the measured diameter. A circular incision is made through the conjunctiva completely around the globe at the selected region and the conjunctiva and

Tenon's capsule are reflected to expose the substance of the sclera. For greatest accuracy in positioning the scleral expansion band, the diameter of the sclera as exposed by the reflection of the conjunctiva and Tenon's capsule is measured at a point 1.5 mm
5 posterior to the limbus. Alternatively the size of sclera can be measured before the conjunctiva is incised. The band is then placed on the surface of the globe and sutured thereto preferably with interrupted stitches as conventional in ophthalmological surgery. In order to facilitate suturing the band to the sclera, the band
10 may be perforated with holes. For example, a total of sixteen holes may be placed equidistant around the band.

It is also possible to expand the sclera in the region of the ciliary body by positioning a band within or just inside the sclera, the band having a diameter just greater than the natural
15 diameter of the overlying tissue. In this way the interior band will expand the overlying tissue and produce the desired result of increasing the effective working distance of the ciliary muscle.

Other methods for increasing the diameter of the sclera in the region of the ciliary body may also be used in the treatment of
20 presbyopia according to the invention. The sclera itself is a tough strong capsule comprised largely of collagen and held in a rigid state of tension by the internal ocular pressure (IOP). If the sclera is weakened in the area adjacent to the ciliary body, the

IOP will cause that portion of the sclera to bulge outward, thereby increasing the diameter of the ciliary body and increasing the distance of the ciliary body from the lens. Any method of weakening the structure of the sclera is suitable. For example enzymatic degradation of the collagen by collagenase may be employed. The collagenase may be carefully injected in to the appropriate region of the sclera or may be applied topically. Equivalent enzymes or other chemical treatments that weaken the collagen of the sclera can also be used. Certain antimitotic drugs such as mitomycin are known to cause a softening of the sclera (scleromalacia), and these drugs can be applied to the region of the sclera adjacent to the ciliary body, either topically or by injection, to effect the desired weakening of the sclera. Other antimitotic pharmaceutical agents, e.g., methotrexate, azaribine, 6-mercaptopurine, 5-fluorouracil, daunorubicin, doxorubicin, cytarabine, the vinca alkaloids and the like, can also be applied to the sclera to weaken it and permit it to be expanded by the intraocular pressure.

Alternatively, the sclera in the region of the ciliary body may be weakened by surgical means.

The sclera may be thinned or weakened by the surgical removal of a portion of its collagenous substance, as, for example by ablating a portion of the thickness of the sclera. This thinning can be accomplished by paring or by abrading the surface or by

ablating the surface with laser irradiation. The sclera can also be weakened by incisions carefully placed at appropriate angles in the region overlying the ciliary body. The diameter of the sclera overlying the ciliary body can also be increased by making a
5 complete periglobular incision and grafting into the incision appropriate tissue and/or physiologically acceptable structural material to increase the dimensions of the sclera. Thus an artificial scleral alloplant made of purified human collagen may be engrafted into such an incision. Other known biocompatible
10 materials, e.g., poly(ethylene terephthalate), that are conventionally used in the construction of prosthetic devices may also be used for engrafting into such an incision. It is also possible to excise a small strip of sclera from the region overlying the ciliary body and replace it with a scleral alloplant
15 as described above to provide an appropriate increase in the diameter of this region.

FIGURE 10 shows a diagram of an exemplary laser 1000 of the type capable of treating various eye diseases in accordance with the principles of the present invention. Such eye diseases include
20 presbyopia, hyperopia, primary open angle glaucoma, and ocular hypertension. Laser 1000 may be any suitably arranged laser, for instance, any of a carbon dioxide laser, a helium-neon laser, a helium-cadmium laser, an argon ion laser, a krypton ion laser, a

5 xenon laser, a nitrous oxide laser, iodine laser, a holmium doped yttrium-aluminum garnet laser, an excimer laser, a chemical laser, a harmonically oscillated laser, a dye laser, a nitrogen laser, a neodymium laser, an erbium laser, a ruby laser, a titanium-sapphire laser and a diode laser.

10 Laser 1000 is operable to weaken the sclera of an eye in the region of the ciliary body to thereby increase the effective working distance of the ciliary muscle of the eye and increase the amplitude of accommodation of the eye, all in accordance with the principles of the present invention.

15 Exemplary laser 1000 illustratively includes a power supply 1010, laser beam generator 1020 and a controller 1030. Exemplary power supply 1010 supplies power to laser 1000. Exemplary laser beam generator 1020 is operable to generate a narrow coherent beam of radiation. Exemplary controller 1030 is operable to control the intensity of the laser beam generated. The laser beam may be one of ionizing radiation or non-ionizing radiation.

20 Laser 1000 is operable to weaken the sclera of the eye in the region of the ciliary body, for instance, by (i) abrading the sclera with laser irradiation, (ii) ablating the sclera with laser irradiation, (iii) incising the sclera with laser irradiation, (iv) incising the sclera at select angles with laser irradiation, and (v) decomposing partially collagen fibers in the sclera.

Exemplary laser 1000 is illustrated with three stages. Exemplary stage 1: in a laser, energy is stored in a "lasing" medium, which may be a solid, liquid or gas; the energy excites atoms in the medium, raising them to a high-energy state such that an excited atom releases a light ray (here, electrons in an electric current excite the gas atoms). Exemplary Stage 2: a ray of light from the excited atom strikes another excited atom, causing it also to emit a light ray; these light rays strike more excited atoms, and the process of light production grows, such that mirrors at the ends of the tube reflect the light rays so that more and more excited atoms release light. Exemplary Stage 3: as each excited atom emits a light ray, the new ray vibrates in step with the ray that strikes the atom; all the rays are in step, and the beam becomes bright enough to pass through the semi-silvered mirror and leave the laser; the energy is as laser light.

Turning to FIGURE 11, shown is an exemplary flow diagram (generally designated 1100) of an exemplary method of operating a laser in accordance with the principles of the present invention. The discussion of FIGURE 11 is made concurrently with reference to FIGURE 10 and laser 1000.

Exemplary method 1100 operates laser 1000 to treat presbyopia, hyperopia, primary open angle glaucoma and ocular hypertension. Initially laser 1000 is enabled, causing laser beam generator 1020

to generate a laser beam whose intensity is controlled by controller 1030 (process step 1110). Laser 1000 is used to irradiate the sclera of an eye in the region of the ciliary body in accordance with the principles of the present invention to thereby
5 weaken the sclera of the eye and to increase the effective working distance of the ciliary muscle of the eye (Step 1120).

This step of irradiating the sclera of an eye in the region of the ciliary body may comprise (i) abrading the sclera with laser irradiation; (ii) ablating the sclera with laser irradiation;
10 (iii) incising the sclera with laser irradiation (including at select angles); and (iv) decomposing partially collagen fibers in the sclera.

Any irradiative treatment with ionizing or non-ionizing radiation that weakens the sclera may be used. For example
15 irradiation with electrons, protons, or x-rays and the like, or irradiation with ultrasonic waves or the like can be used. Thermal burning and/or scarring in the appropriate area may also be used to induce an enlargement of the sclera in the area adjacent to the ciliary body.

20 Treatments designed to weaken the sclera in the region overlying the ciliary body can also be combined with application of the scleral expansion band of the invention. For example, the sclera can be treated with collagenase, mitomycin, or other

antimitotic agent, as described above and the scleral band subsequently applied and fastened to the sclera. The band itself, its components and/or the sutures may also be coated or impregnated with the sclera-weakening agents whereby they can come into contact with the sclera and exercise their effect when the band is applied. In some cases the band may be later removed to leave the patient with a suitably expanded sclera.

Just as the distance between the ciliary body and the equator of the lens can be increased by expanding the sclera and ciliary body, the distance can be maintained and the progress of presbyopia arrested by stopping the growth of the crystalline lens. While such a treatment cannot reverse the course of presbyopia, it can arrest the progress of the symptoms, and is appropriate for treatment of patients in whom the presbyopia has not progressed very far. The growth of the lens can be arrested by administration of pharmaceutical compounds which stop cell division and growth. For example, colchicine can be administered to prevent cell division, thereby stopping the growth of the lens. Conventional antimitotic drugs may also be used to arrest the growth of the lens. Such drugs are well known and include, for example, methotrexate, azaribine, 6-mercaptopurine, 5-fluorouracil, daunorubicin, doxorubicin, cytarabine, the vinca alkaloids and the like. Such drugs may be applied topically or by injection into the appropriate structure of

the eye where they will come into contact with the lens and exercise their pharmacological activity. If the drugs are sufficiently free of side effects, they may also be administered systemically, either by mouth or parenterally. The growth of the lens may also be arrested by physical treatments directed at the newly forming cells in the epithelium of the lens, particularly in the equatorial region of the lens. Treatments that prevent further division of the cells are appropriate for preventing further lens growth. Thus, the epithelial cells may be heated by laser radiation or ultrasonic irradiation, or inactivated by laser irradiation with a laser capable of directly disrupting chemical bonds within the structures of the cells. Sharply focused laser beams or irradiation with microscopic diode lasers positioned close to the equator of the lens are suitable for applying this radiation. Irradiation with electrons, protons, x-rays or the like may also be used to stop the further division of the epithelial cells of the lens. These treatments should be directed only to the portion of the lens structures that are composed of cells capable of dividing and should not be directed toward the substance of the lens where they might provoke the formation of cataracts.

Surgical methods that work more directly on the ciliary muscle may also be used to increase the effective working distance of the muscle. The body of the muscle itself may be shortened, for example

by scarring induced by irradiation with suitable laser beams or beams of ionizing or non-ionizing radiation such as ultrasound or electron or proton beams or x-rays. The effective working range of the muscle may also be increased by moving its insertions to increase the distance between them. The ciliary muscle is inserted anteriorly into the scleral spur and posteriorly into the choroid. Treatment of either of these insertions to cause them to move apart from the complementary insertion will increase the effective working range of the ciliary muscle and improve the amplitude of accommodation according to the invention. Selective scarring of adjacent tissue planned to cause retraction of either insertion of the ciliary muscle is effective to accomplish this result. The scarring can be accomplished by thermal or radiative treatment of the tissue by the means and methods generally outlined above.

The method of the invention which increase the amplitude of accommodation may also be of benefit in treatment of hyperopia in certain patients. Some youthful hyperopes can achieve relatively normal vision by compensating for their hyperopia through the natural accommodative ability of the eye. However, as this ability declines with age, they find that it becomes more difficult to attain normal vision by this process, and they begin to experience headaches and other symptoms, even at an age somewhat less than usual for the onset of presbyopia. Evidently, increasing the

amplitude of accommodation by the method of this invention would be useful in restoring the ability of these patients to compensate for their hyperopia.

5 The method of this invention also has utility in the treatment of primary open-angle glaucoma, which shows a correlation with age in certain individuals. It has been found that, in general, IOP exhibits a linear increase with increasing age. (Armaly, M.F., On the distribution of applanation pressure I. Statistical features and the effect of age, sex, and family history of glaucoma, Archives of Ophthalmology, Vol. 73, pp. 11-18 (1965).) Among the
10 general population is found a group of individuals who develop abnormally high intraocular pressures as a result of primary open angle glaucoma, a disease which is one of the most prevalent causes of blindness in the world. According to the theory of this
15 invention, the linear increase in IOP with age is a direct result of the decrease in distance between the lens equator and the ciliary muscle and the resulting linear decrease in the effective pull of the ciliary muscle. Since the ciliary muscle inserts into the trabecular meshwork, the decrease in pull will decrease the
20 size of the trabeculum and/or the drainage pores and result in a linear increase of intraocular pressure with age. In this view, the patients who develop primary open angle glaucoma may have a congenital predilection to narrower pores and/or smaller trabecular

meshwork, so that when the ability of the ciliary muscle to exert force declines, after the age of 40 or thereabouts, they tend to develop excessively elevated IOP.

5 The method of the invention which increases the effective working distance of the ciliary muscle, and thereby increases the force that it can exert when it contracts, restores the level of force which the ciliary muscle exerts on the trabecular meshwork to a value characteristic of a more youthful eye. In this way it is expected that the tendency of an eye that is disposed to develop
10 primary open angle glaucoma as it ages would be overcome and the onset of this disease would be prevented or at least postponed.

The ability of the ciliary muscle to exert tension on the lens by means of the zonules can also be increased by shortening the zonules, a procedure which increases the effective working range of
15 the ciliary muscle. This shortening can be produced by heating the zonules by ultrasonic irradiation or laser irradiation. The zonules may also be treated with electrons, protons, x-rays and the like which may cause changes in the structure of the zonules resulting in shortening. The shortening of the zonules may also be brought
20 about by application of chemical compounds that act to cause a shrinkage of the collagenous zonules.

The invention will be illustrated by the following examples which are intended for illustration only and are not to be

interpreted as limiting the claims.

EXAMPLE 1

This example illustrates the feasibility of increasing the diameter of the ciliary body by suturing an external band to the sclera.

Human cadaver eyes were selected for experimentation. The diameter of the sclera was measured using a shadow graph at distances of 1.5 millimeters and 3.5 millimeters from the limbus. The diameters were found to be 16.2 mm and 20 mm respectively. Bands were made from medical grade poly(methyl methacrylate) having a low frustoconical shape and a radial thickness of 0.5 mm. The internal diameter of the larger (posterior) side was 20 mm, and the smaller (anterior) diameters varied from 14.5 mm to 18.0 mm in 0.25 mm steps. A band was selected having a major diameter of 20 mm and a minor diameter of 18.0 mm. The band was placed on the sclera of a human cadaver eye so that the 18.0 mm diameter end of the band was 1.5 mm from the limbus and the 20 mm diameter end was 3.5 mm from the limbus. The band was sutured through the holes with 16 interrupted 6-0 polyester (Mersilene, Ethicon, Inc.) stitches to the sclera. This resulted in a clearly observable stretching of the sclera in the region of the ciliary body. The pupil became dilated by about 1.5 mm. Since the iris inserts into the ciliary body, the

pupillary dilation demonstrated that the induced scleral stretching was also moving the ciliary body outward, thereby increasing its diameter and its distance from the equator of the lens.

5 EXAMPLE 2

 This example illustrates the treatment of presbyopia in patients.

 Following informed consent, six presbyopic patients with otherwise normal eyes, except for minimal refractive errors, had scleral expansion bands of the invention sutured to the sclera in the region of the ciliary body. Their age ranged from 47 to 60 years, there were three males and three females, and their preoperative amplitude of accommodation varied from 1.3 to 2.7 diopters. The ophthalmological examination including biomicroscopy was normal. Following local infiltration into the conjunctive with prilocaine HCl for injection (Citanast (Astra), 40 mg/ml), a 360 degree limbal based peritomy was performed and the sclera was cleaned of Tenon's capsule. Using vernier calipers, a distance of 1.5 mm posterior to the limbus was measured from the limbus and the scleral diameter was measured at that location. A band of the type made in Example 1 was selected having a minor diameter of from 0.5 mm to 1.5 mm greater than the measured diameter of the sclera. The band was sutured to the sclera with 16 interrupted 6-0 polyester

(Mersilene, Ethicon, Inc.) stitches. The patients were given antibiotic-steroid drops to use for five days. Postoperatively, the patients were followed daily for five days and then weekly. The results are presented in Table 1 below.

5

TABLE 1

Preoperative and Postoperative Amplitude of Accommodation

Patient No.	Age (yr)	Sex	Preoperative		Postoperative	
			Near Point (cm)	Amplitude of Accommo- dation (diopters)	Near Point (cm)	Amplitude of Accommo- dation (diopters)
1	55	M	75	1.3	9	11.1
2	50	F	45	2.2	10	10.0
3	47	F	37	2.7	16	6.25
4	56	M	56	1.7	9	11.1
5	60	F	38	2.6	12	8.3
6	46	M	40	2.5	17	5.8

30

The invention having now been fully described, it should be understood that it may be embodied in other specific forms or variations without departing from its spirit or essential characteristics. Accordingly, the embodiments described above are to be considered in all respects as illustrative and not

restrictive, the scope of the invention being indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are intended to be embraced therein.

11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224